Aircraft Aeroelasticity

A study of aeroelastic effects on aircraft structures using finite element analysis

Problem

Aircraft structures must be strong and lightweight. Some structures exhibit a strong coupling between their elastic and fluid responses. At high aircraft speeds, an aeroelastic response may have a negative effect on the structures' intended aerodynamic, structural, and stability parameters.

Solving with Software

SU2, a fluid solver, finds the pressure on an airfoil by modeling the airfoil and a surrounding area as a mesh. Hundreds of sub-iterations are required to converge to an accurate value for pressure and lift. NASTRAN software finds the deformation of the structure due to pressure. This change in geometry requires the pressure from to flow to be calculated until convergence.

Implementation

SU2 and NASTRAN are completely different software that do not automatically integrate together. Fortunately, a Matlab script can be used to call each software. This Matlab script is able to direct the inputs and outputs of each software so that they iterate run one after another until convergence. This creates a cycle of nested iterations which is best run on a super computer.

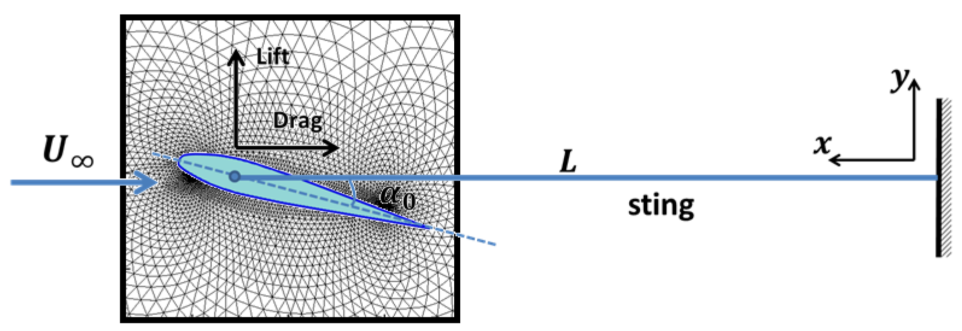

Figure 1: An airfoil attached to a beam will bend the beam due to the lift vector.

Iteration Process Overview

SU2

- Fluid Solver
- Finds flow and pressure at every point given a Mach number, airfoil, and environmental conditions

Inputs: Airfoil, Flow Conditions
Outputs: Pressure Distribution

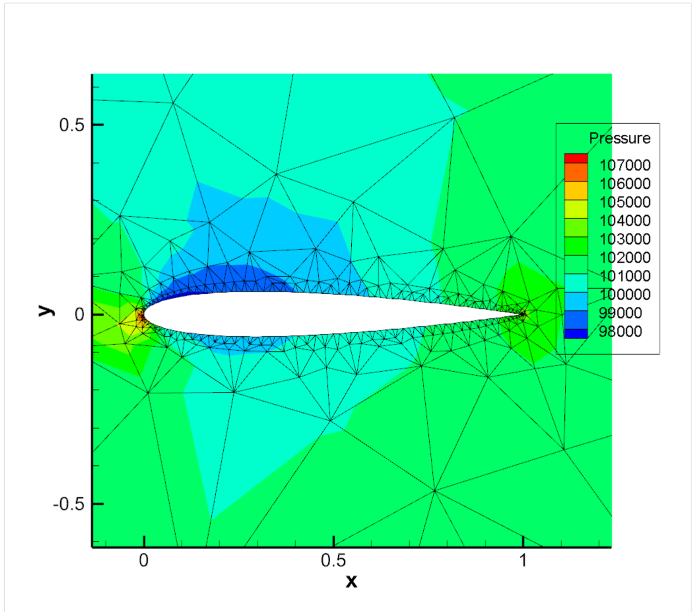

Figure 2: Outputs from SU2 visualized in TecPlot360

NASTRAN

- Structures Solver
- The pressure at every point from fluid analysis deforms the structure at every point. This changes the shape of the airfoil

Inputs: Pressures on Airfoil
Outputs: Deformed Airfoil

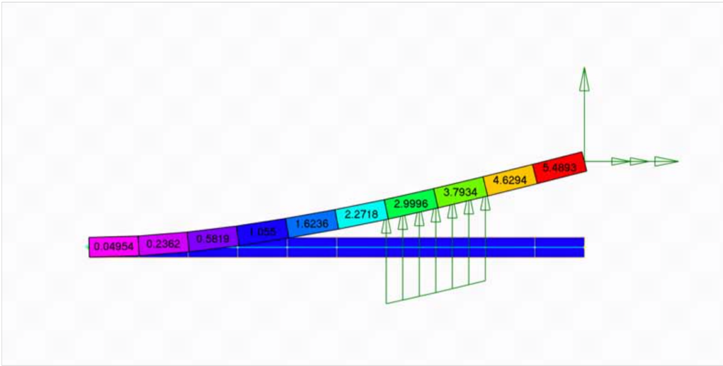

Figure 3: Outputs from NASTRAN showing a theoretical deformation of an airfoil due to pressures across the bottom surface

0.1 Mach Convergence

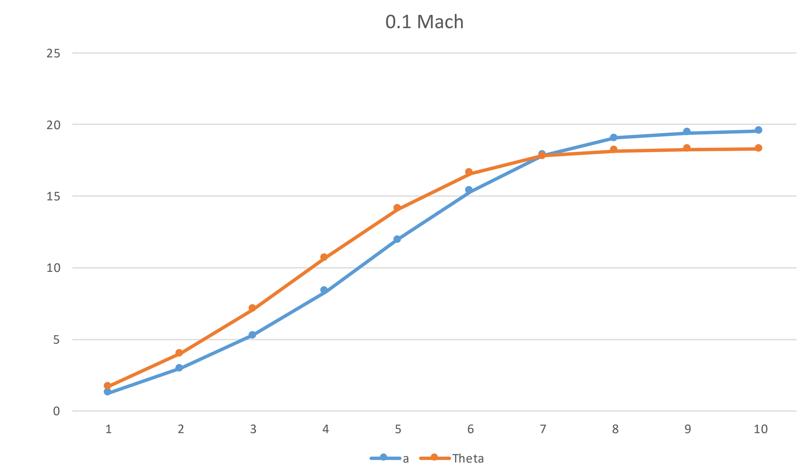

Figure 4: An airfoil was attached to a beam to find the angle of attack in which it settles. After a certain number of iterations, the angle of attack converges to a steady value.

0.5 Mach Convergence

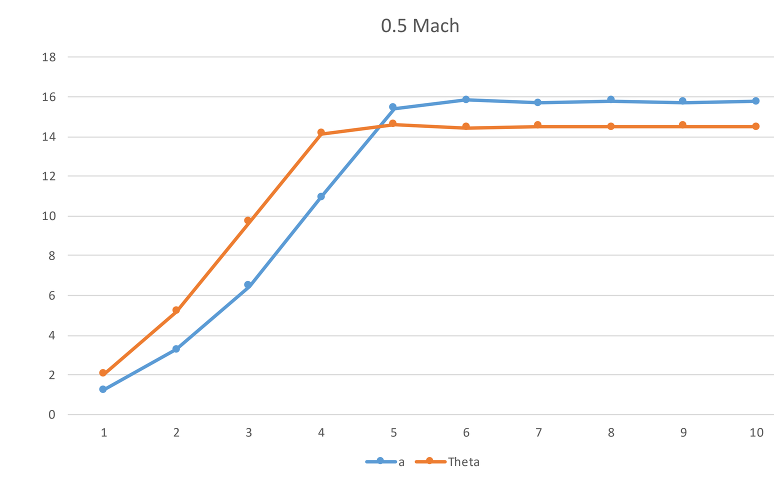

Figure 5: At Mach 0.5, the convergence occurs more rapidly than Mach 0.1.

Mathematical Steps

1. Traction on the structural boundary is based on the pressure distribution (fluid response)

$$\boldsymbol{\Phi} = [\boldsymbol{\sigma}]\,\boldsymbol{n} = -p\boldsymbol{n}_{fs}$$

2. Flexible fluid-structure boundary deforms due to structural loads

$$x_{fs} = x_s + u_x,$$

$$y_{fs} = y_s + u_y.$$

3. Fluid boundary conditions are imposed on the deformed boundary

$$\vec{\boldsymbol{u}} \cdot \hat{\boldsymbol{n}}|_{\Gamma_{fs}} = (u n_x + v n_y)|_{\Gamma_{fs}} = 0$$

4. Impose the fluid boundary conditions for flow analysis using weak approach

$$\widetilde{F_k} = (F_k \hat{\imath} + G_k \hat{\jmath}) \cdot \hat{n}_k$$

This process repeats until convergence

Results

Based on a model using an airfoil attached to a rigid beam to find the steady state angle of attack (due to the deformations on the beam), it can be seen that the process converges in under 10 iterations. However, because each iteration requires many sub-iterations to find the pressure and deflection, the overall process is lengthy.

Yunxiao Liu & Dr. Mandar Kulkarni